UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

COURSE SYLLABUS

Quantum Electronics

2526-1-F1703Q039

Aims

The course aims to provide the fundamental notions on the interactions between electromagnetic radiation and matter at the atomic and molecular level. It explores how quantum mechanics influences the behavior of electrons and other charge carriers in electronic devices and systems. The electronic states of materials and devices will be studied through the discussion of their architectures and measurements of the optical, electronic and magnetic properties in order to understand the potential applications of quantum materials in quantum technologies.

The expected results at the end of the course are:

1. *Knowledge and understanding*
   Students will acquire knowledge in the field of materials and quantum phenomena emerging from the confinement of matter along one or more directions in space, and methods for the preparation and characterization of devices that allow the exploitation of such phenomena in electronics for quantum technologies.

2. *Applied knowledge and understanding*
   Skills in techniques for the characterization of materials, and methods for the realization of devices for spintronics, sensing and quantum computing.

3. *Making judgments*
   Students will acquire judgment skills that will enable the to identify the key properties of materials that allow the development of advanced and high-performance devices, and to discern between their potentialities and limitations.

4. *Communication skills*
   Students will acquire the terminology and language necessary to be able to describe the properties of advanced materials for quantum electronics as well as the methods for the preparation and realization of devices in nanotechnology.

5. *Learning skills*
   Students will acquire the tools that will allow them to continue their studies independently through the use of investigative methods for the study and research of advanced materials and devices.

Contents

• Introduction: Electronics for modern quantum technologies
• Quantum transport in low dimensional structures
• Spintronics
• Methods for the generation and manipulation of coherent optical radiation and microwaves (with laboratory)
• Emergent functionalities: topological magnetism

Detailed program

INTRODUCTION
• Electronic devices for the modern quantum technologies. Overview of course pre-requisite, lecture contents, textbooks/literature, and assessment methods.

QUANTUM TRANSPORT
• Conduction mechanism in low dimensional systems. Elastic Resistor. Linear regime. Ballistic, diffusive and quasi-ballistic transport.
• General formalism for conductivity. Interface resistance. Two perspectives for conductivity. Boltzmann equation.
• Designing rules for an efficient Nanotransistor. Quantized conductance. Quantum Point Contact (QPC). Buttiker - Landauer formalism.
• Integer and fractional Quantum Hall effect. Graphene.
• Coherent and incoherent tunnelling in a double barrier.
• Single Electron Transistor: theory, operation and applications. Charge sensing with QPC: electrometer.

METHODS FOR THE GENERATION AND MANIPULATION OF COHERENT OPTICAL RADIATION AND MICROWAVES
• Principle of laser emission and short pulse generation.
• Optical resonators, waveguides, and integrated circuits,.
• Microwave emitters and masers; Radio-Frequency cavities.
• Laboratory experiences.

METHODS FOR ELECTRON SPIN GENERATION, DETECTION and MANIPULATION
• Spin in a Quantum Dot. Excited states spectroscopy. Field induced S-T transition. Bipolar spin filter. Spin to charge conversion methods.
• Quantum Non – Demolition with Double Quantum Dots. Charge stability diagram. Charge sensing with double dots.
• Spins in two double QDs. Pauli spin blockade. Spin dephasing mechanisms.
• Electron spin resonance. Methods for microwave, electrical and optical manipulation of electron spins.
• Optical manipulation of electron spin with NV centers in diamond.

SPINTRONICS DEVICES AND APPLICATIONS
• Theory of conduction in magnetic layers structures. Spin transport across interfaces.
• Magnetoresistance effects: Anisotropic Magnetoresistance (AMR). Giant Magnetoresistance (GMR). Tunnelling Magneto-resistance. Magnetic tunnelling junctions.

• Electrical Spin detection and manipulation with lateral spin valves.
• Universal memory magnetic random access memory (MRAM).
• Spin Transfer Torque (STT). Spin injection magnetization switching (SIMS) with Nanopillars.
• Datta-Das Spin Transistor.

EMERGENT FUNCTIONALITIES: TOPOLOGICAL MAGNETISM
• Topology in condensed matter and chiral conduction.
• Topological magnetoelectric effects and topological spintronics.
• Néel-type and Bloch-type magnetic domains and skyrmions.

Prerequisites

Basic concept of quantum mechanics, physics of semiconductor, and solid state physics courses (or equivalent).

Teaching form

26 two-hours lectures , in person, Delivered Didactics.
4 hours of laboratory experiences.
Frontal lectures and exercise sessions using slides and/or blackboard.

Textbook and teaching resource

1. Datta S. (2013) Electronic transport in mesoscopic systems, Cambridge University Press
2. T. Shinjo (2009), Nanomagnetism and Spintronics, Elsevier
3. J. Sto?hr and H.C. Siegmann (2006) Magnetism: from fundamentals to nanoscale dynamics. Springer, Berlin
4. Orazio Svelto (2007), Principle of Lasers (Fourth Edition), Springer, Berlin
   Additional references will be given during the lectures. Slides will be made available to the students through the present e-learning platform.

Semester

First semester (from September to January)

Assessment method

Students’ knowledge will be evaluated through an oral exam focusing on the topics discussed during the course with presentation of quantitative analyses, equations, graphs, and schemes.
The competence and evaluation criteria will be based on the knowledge and the communication skills gained in the context of the topics studied. There will not be available partial examinations.

Office hours

From Monday to Friday at any working hour (an appointment should be arranged with the teacher by email).

Sustainable Development Goals

QUALITY EDUCATION | INDUSTRY, INNOVATION AND INFRASTRUCTURE